LOOK ACADEMIC PUBLISHERS
OPEN ACCESS

INTERNATIONAL JOURNAL OF ENVIRONMENTAL & SCIENCE EDUCATION
2016, VOL. 11, NO. 14, 6409-6432

Geological Structure of the Basement of Western and Eastern Parts of the West-Siberian Plain

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ABSTRACT

The U-Pb dating (SHRIMP-II on zircon) was obtained for the first time from the basement of the West Siberian Plain in the Western half of the region. It is established that a large part of the protolith of the metamorphic depth in the Shaim-Kuznetsov meganticlinorium contained sedimentary late - and middle-Devonian rocks (395-358 million years). Probably, greywackes served as a substrate of metamorphic rocks substrate, which were formed largely in the erosion of ophiolitic association rocks. The U-Pb method helped to specify late carbonic age of granite plutons composing the Shaim-Kuznetsov meganticlinorium. It turns out that the kernels of anticlinoria are not Precambrian blocks, but Paleozoic magmatic and metamorphic complexes, i.e., the formations of the lower and middle part of the crust. In the Eastern part of Western Siberia, the tectonic zoning of the basement of East Khanty-Mansiisk Autonomous district is held and 8 submeridional structural-formational zones are determined with different sets and structure of composing formations, history of geological development and physical regions. On the basis of generalization and analysis data, we have compiled a new geological map of the pre-Jurassic base of the Eastern part of the Khanty-Mansiisk Autonomous district, significantly refining the predecessors' maps.

KEYWORDS
West-Siberia, geological map of the basement, metamorphic rocks, granite, U-Pb age

ARTICLE HISTORY
Received 21 December 2015
Revised 10 May 2016 Accepted 29 May 2016

Introduction

The West Siberian oil and gas megabasin is (and will remain) a major supplier of oil and gas in Russia, i.e. the main "geological and economic" region of the country. Therefore, a comprehensive study of Western Siberia, including its basement, continues for more than half a century (Bogush et al., 1975; Kontorovich et al., 1975; Krasnov et al., 1993; Bochkarev et al., 2003; Fedorov et al., 2004; Ivanov et al., 2007; Kontorovich, 2007; Eliseev et al.; 2008, Ponomarev, 2011).

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In the West Siberian Plain, as it is known, traditionally there are three main structural levels:

1) Folded basement made by formations of almost exclusively Paleozoic age;
2) Rift (or intermediate) structural level represented by basalts, sometimes by basalts and rhyolites of the early Triassic age, which are replaced upward in the section by the terrigenous depth of middle and late Triassic age;
3) Orthoplatform cover, composed mostly of Jurassic rocks, almost undisturbed sedimentary depth, which contain almost all deposits of hydrocarbons in Western Siberia. The capacity of the cover increases in the North, reaching 6 km and more.

The first two levels are usually called the pre-Jurassic bases of West Siberian Plain.

Interest to the hydrocarbon deposits, associated with the reservoirs of preJurassic base of West Siberian Plain, occurred immediately after the discovery of industrial gas and oil deposits in the 60s of the last century in Berezovsky and Shaim districts of the Transurals region. In this region, the first wells installed the productivity of the upper part of the Paleozoic complex (Kontorovich et al., 1975). Today, the Triassic and Paleozoic formations of pre-Jurassic base of West Siberian Plain opened more than with 5 thousand wells, very unevenly distributed, mainly in the southern and central regions of Western Siberia. Stratigraphy (as well as age and material composition) of the Paleozoic depth of basement are studied insufficiently. The only exceptions are the small blocks of carbonate Devonian-Carboniferous deposits (Bogush et al., 1975; Elkin et al., 2001).

Aim of the Study

The aim of this study is the creation of spatial models (geological maps and multi-layer models in geographic information systems - GIS) and the geodynamic reconstruction of the rocks complexes formation of pre-Jurassic basement in the Eastern and Western part of the West Siberian mega basin.

Research questions

To achieve this goal, a solution to several problems is planned. In particular, what is the age of the intrusive and metamorphic rocks in the pre-Jurassic basement at the studied region? What is the spatial structure of pre-Jurassic basement of West Siberian Plain? In which geodynamic conditions the formation of rocks occurred in different structural zones of the basement?

Method

To extract zircon in order to determine the age, we crushed the samples, separated them by gravity and magnetic separation, and handpicked grains of zircon. Isotopic U-Pb dating of zircons was carried out in the Center of Isotopic Research VSEGEI (Saint-Petersburg, Russia) on the secondary ion mass spectrometer SHRIMP-II, according to the technique described in (Williams, 1998).

Determination of families and species of fossil foraminifera was carried out by T. I. Stepanov (2012) in Geology and Geochemistry Institute (Ekaterinburg, Russia).

The zoning of the basement of the West Siberian basin is based on the previously proposed semes (Surkov & Trofimuk, 1986; Elkin et al., 2001; Bochkarev et al., 2003; Elkin et al., 2008; Surkov & Smirnov, 2008) taking into account the recent geological and geochronological data, the data from maps of gravitational and magnetic fields and drill-hole cores study.

The development process of discussed cartographic models is based on the electronic database specifically designed to solve tasks based on geological and informational technologies ArcGIS (ArcView. Using ArcView GIS…, 1996) and software applications for various purposes. The model of the geological structure of the Eastern margin basement of the Khanty-Mansiisk Autonomous district is a multilayer metadata structure in vector and raster formats in a consistent absolute geographic space. This provides for "hot" connection of vector layers elements with the attribute database that allows referring to digital and raster information in visual and analytical modes to such map features as well (drill sample and thin rock sections photographs, stratigraphic columns, dipmeters, etc.), seismic profile (images of temporary sections in various transformations), geological section, etc.

The Zoning of the West-Siberian Megabasin Basement

Since 30-ies of the last century, more than thirty constantly clarifying schemes of basement zoning of the West Siberian Plain were developed (Surkov & Trofimuk, 1986; Elkin et al., 2001; Bochkarev et al., 2003; Elkin, et al., 2008; Surkov & Smirnov, 2008), which strongly differ in the interpretation of different authors (see, for example, very different patterns (Elkin et al., 2008) – Figure 1 and (Surkov & Smirnov, 2008), published in one book). A common feature of the schemes is continuing of surrounding Paleozoic fold belts and their structuralformational zones in the basement of Western Siberia. Almost all researchers agree that the basements of the Western part of the West Siberian Plain are the structural zones of the Eastern sector of the Urals, and the basement of the East slabs are complexes of the Siberian Plain and its folded framing. In addition, a common schemes feature of the basement zoning of the West Siberian Plain is the presence of a large block at the East of Urals, gradually nipped to the North (Figure 1). The main megazones (or domains) are separated by large sutures – Valerianovsk and Chara.

The drill sample of Siberian domain is the Siberian Plain and surrounding folded regions, among which the three primary facies megazones are reconstructed on the basis of formational analysis, and isotopic and paleontological data (Elkin et al., 2001; Elkin et al., 2008). They form a single facies series, describing the environment of sedimentation on the Siberian continent, and near it, with a gradual deepening to the West. Therefore, megazone II (Figure 1) is composed predominantly of shallow-water terrigenous-carbonate formations of the upper Cambrian – lower classes of the middle Carboniferous, continued shelf of the Siberian continent.

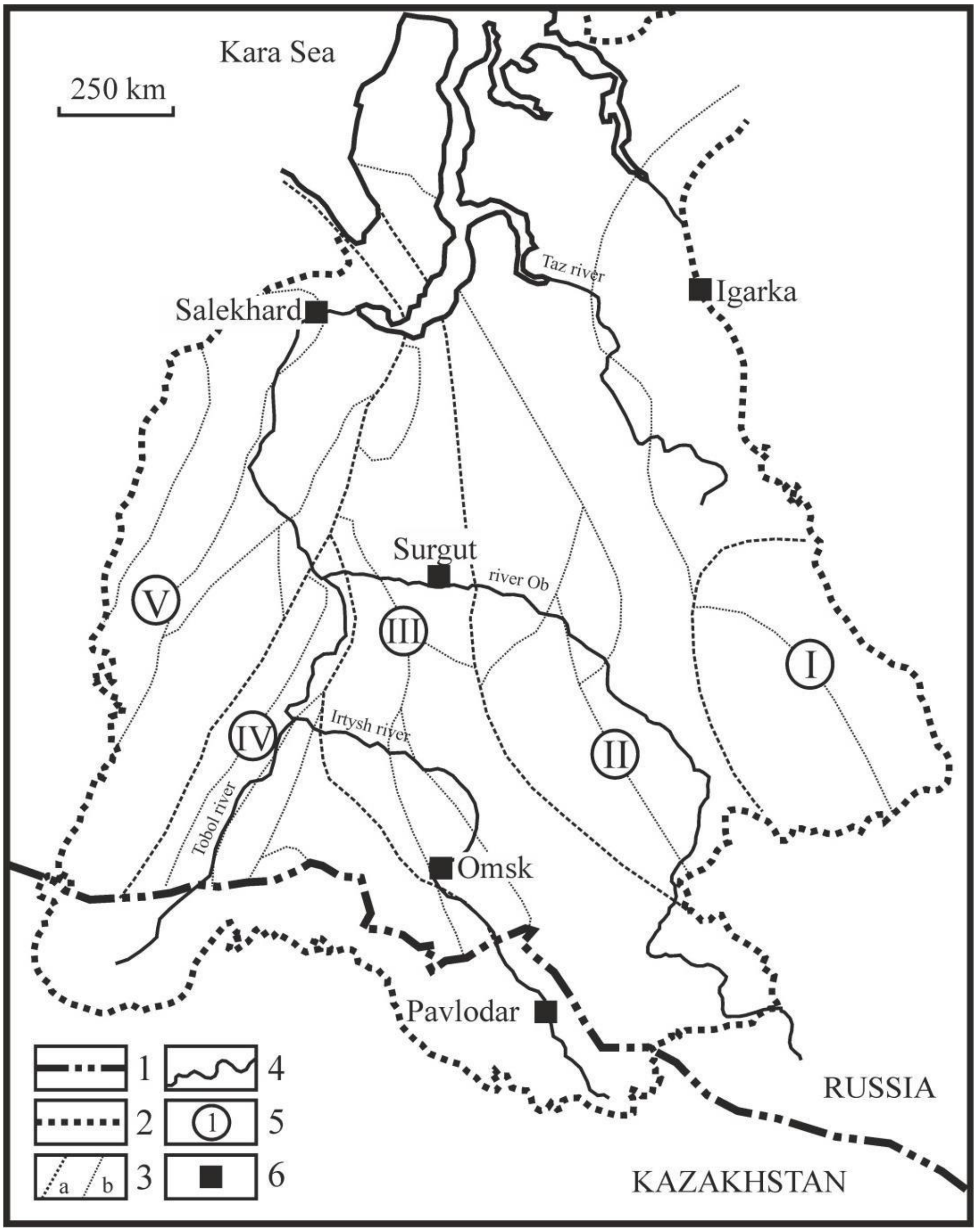

Figure 1. Facial regions and megazones in the structure of the basement of the West Siberian Plain (Elkin et al., 2008). Legend: 1 – the border between Russia and Kazakhstan, 2 – border of the West Siberian Plain, 3 – the border between megazones (a) and (b), 4 – rivers, 5 – room megazone, 6 – cities.

Megazone III presents a predominantly deeper-water facies of the shelf, continental slope, and volcanogenic complexes. In the interpretation (Surkov & Smirnov, 2008) megazone III roughly meets the Central West Siberian block of the earth's crust Late Hercynian consolidation, folded mostly flysch and carbonate formations of the middle Paleozoic. It is assumed (Kontorovich et al., 2003) that all three noted megazones, along with the Siberian Plain are linked by a single Precambrian (Proterozoic-Low Riphean) crystal base. The basement is not opened by wells, and it was assumed (Kontorovich et al., 2008) in the interpretation of several seismic lines at the bottom, at depths below 4 km. that we have Recently been able to confirm the presence of the Precambrian crystalline basement in this part of the West Siberian Plain: Cynarski region at the East of Khanty-Mansiisk Autonomous district (see below).

Since the late Riphean and Cambrian inclusive, have been stretching and fragmentation of the Siberian domain (Elkin et al., 2008). First break all the continental crust with its razvigor probably happened at the turn of the early and late Riphean was formed turbidite complexes and ophiolites. Evidence of the last pulse of the processes of rifting can probably be considered the volcanic rocks of basic composition, revealed well. All terrain-4; its chemical composition they correspond to basalts and back-arc basins MOR (Saraev et al., 2004). The development of the Siberian domain led to the formation of the plain formations, facies deep and shallow shelf, as well as surface deposits.

The ideas about the development of Kazakhstani (megazone IV in Figure 1) controversial issues is much larger. Debated as the assignment to him of certain districts composed of very diverse systems (among which as a whole is dominated by ANDESITES and their calc sinters and carbonate-shale complexes of Devonian-Carboniferous, etc.), and the whole history of the development of this structural unit in Western Siberia. Usually considered (Ergaliev et al., 1995), the South of this megazone is a dive and the Kokchetav block and to the North is Krasnoleninsk arch and both Precambrian block were united, likely in frane. Nevertheless, the assumption of the presence of the Precambrian in the Krasnoleninsk arch is not proven. Note that the granitoids of this domain significantly ancient (440-450 million years, U-Pb method, SHRIMP-II, our data) than in the Ural part (280-290 million years). In the West domain in the early Carboniferous was presumably a narrow shelf, on which there was an accumulation of terrigenous-carbonate sediments of high power (Elkin et al., 2001). Kazakhstan is separated from the Ural part of West Siberian Plain by Valerianovsk suture, which is well manifested in the magnetic and electromagnetic fields and can be traced to a depth of at least 20-30 km (D yakonova et al., 2008). Charskaya suture is located between kazachstanicum and the Siberian domain; the age of the ophiolites of this suture is defined as the boundary of the Visean and Serpukhov centuries, early Carboniferous (Iwata et al., 1977). For these and most other margin faults of the basement of the West Siberian Plain is grounded shear nature (and amplitude shifts – many hundreds of kilometers), connected by paleomagnetic data with the rotation of the Siberian domain relative to the European clockwise (Buslov et al., 2003; Vernikovsky et al., 2009).

The Ural part of the West Siberian Plain (megazone V in Figure 1) is composed of formations of the Eastern, paleostructures sector of the Urals (Peyve et al., 1976; Smith, 1998; Ivanov et al., 2006). On the basis of comprehensive geological-geophysical studies jointly with the deceased Yu. Fedorov (2004) and V. V. by Kormiltsev (2006) was drawn up in sufficient detail (scale 1:200000 and 1:500000) geological-structural map of the pre-Jurassic base in the North-Sosva and Shaim oil and gas regions. The result of mapping of large segments of the territory developed a new structural and formational zones of the basement of the Western part of the West Siberian Plain and, on this basis, generalized geologic map of the Ural part of the pre-Jurassic base of West Siberian Plain.

The border of the Urals and Western Siberia is not only spatial, but also temporal. The immediate border of the Urals and the West Siberian young Plain (i.e. Western Plain boundary) is the discharge into the West side of the North Sosva Graben, extending the Circumpolar region, 350 km in submeridional direction along an “open” Urals (Ivanov et al., 2004). Studies of magmatic and metamorphic complexes, as well as volcanic (including ophiolite), terrigenousshale, carbonate, and other depth of the Urals and the Western half of West Siberia show their undoubted resemblance. In the structure of the base site sets a lot in common with an open Urals. Composition, age and geological structures of many complexes of these two regions is similar. As well as in the

Urals, in the basement of West Siberia, we identified two stages of magmatism of ophiolite – Ordovician and Devonian (Sm-Nd Dating of basalts and gabbros, as well as conodonts and Radiolaria from the interlayers of Jasper). Geochemical characteristics of the mafic rocks suggest that they were formed in island arc (probably telewebinar) conditions.

Along with the similarities revealed significant differences between the Urals and the basement of the West Siberia. Therefore, within the open of the Urals, with all the diversity in observed systems of faults, most clearly manifested submeridional left shifts of the late Paleozoic age. In the Shaim region identified unknown in the Urals, a major margin system of right shifts West-North-West strike to cause stepwise displacement of the main structures of the region. This system of shifts has been generated mostly in the early-middle Triassic (and to some extent later), probably as a result of the latitudinal extension of the region and lowering its Northern parts, which formed the first system of the Triassic grabens of Western Siberia filled volcanogenic and terrigenous-volcanic depth, and then the whole of the West Siberian oil and gas megabasin. An important difference is a much more extensive development (as compared to the Urals) volcanic depth of the Triassic in the basement of the West Siberian Plain.

Ophiolites and other mafic-ultramafic complexes that represent fragments of the crust of the oceanic type, is widely developed in the basement of the West Siberian Plain (especially in its Central and Western parts), usually situated along major faults separating structural-formational zones of various types (Dobretsov, 2003; Surkov &, Trofimuk, 1986). The ophiolites form is often not a single breakdown, and are represented mainly by fragments, tectonically crowded with other depths. The most representative Paleozoic ophiolite complex, represented by blended serpentinites, gabbroids, plagiogranites, and basalts with interbedded Jasper described between the villages of Chaim and Supra, within the limits of Shaim oil and gas district the Ural megazone. Here in Jasper, the Late Ordovician radiolaria and conodonts were found (Ivanov et al., 2007). These are the most ancient found complexes of the basement of the Western half of West Siberia (possibly of the same age are dated by chitinozoa, as the Ordovician – lower Silurian terrigenous black shale sediments, formed, probably, in the environment of the continental slope and the foot). The lower structural elements of the ophiolites and the ultrabasic rocks are usually fully serpentinized, but in places contain relics of the original rock. Poorly altered spinel lherzolites are studied by (Ivanov et al., 2009; Simonov et al., 2012) within the Tours region Shaim district. Their compositions fall within the region associated with approximately 5% degree of melting of MORB-basalts from the primary nondepleted mantle source. Temperature of formation of species estimated as 11001200oC, pressure of 10.5 kbar. Lherzolites are characterized by higher contents of Nickel and chromium close to the rocks of the ophiolite association. Apparently, the spinel lherzolites are the relics of the melanocratic bases of early Paleozoic (Urals?) paleo-ocean.

The end of the Paleozoic geodynamic history of the region was the conflict, accompanied by folding, a tectonic clustering, and intrusion of granite plutons, metamorphism, and formation of new continental crust. The age of these major events, consolidated Paleozoic complexes throughout the vast territory of the future West Siberian megabasin, is determined (on the basis of the number of RbSr isochrone and our other data) in the Ural part of the Plain as early Permian. Relatively low values of 87Sr/86Sr in granites of the number of regions (Isr=0.7046-0.7047) Western Siberia indicate that the substrate for melting these granitoids were, apparently, Paleozoic complexes with a significant proportion of the mantle, i.e. the oceanic and island arc material, tectonically crowded during the late Paleozoic collision.

The Geological Structure of the Basement of the Transurals Region in Western Siberia

One of the major unsolved problems of Geology of the basement of Western Siberia is the issue of the amount and even the presence of Precambrian formations in the pre-Jurassic base of the Plain, especially its Western half. In accordance with all existing stratigraphic schemes of dismemberment and correlation of sediments of the basement of Western Siberia, the most ancient formations in the region are the metamorphic depth composing the drill-hole core (Solutions of the Interdepartmental meeting..., 1999). So according to (Elkin et al., 2001), the base section of Tagil SFR (structural-facies region) is overlain by crystalline shale rocks and gneisses; Berezov-Sartyninsky, Sherkalinsky and Shaim SFR – meta-orthoschists, Krasnoleninskiy SFR – chlorite-albite, biotitechlorite-carbonate-quartz shale rocks with a capacity of more than 100 m. All these metamorphic depth are considered by Elkin et al. (2001) as the undifferentiated Precambrian. However, there is no objective evidence of preCambrian age metamorphic depth described territory of Western Siberia. The most detailed mapping of the basement was held (Ivanov et al., 2003) in the Shaim district (scale 1:200000); we investigated and age of metamorphic complexes belonging to the earlier Precambrian. Metamorphic depth compose the graniteshale rock axis, known as the Shaim-Kuznetsov meganticlinorium (margin is characterized by a negative gravimetric anomaly). Local negative anomalies within this structure are interpreted by us as of the late Paleozoic blocks of granitoids and framing of these anomalies – how enclosing metamorphic shale rocks. The results of this interpretation are consistent with the drilling data.

Recently, we have obtained new data on rocks composing the "granite-shale rock axis" in Shaim oil and gas district. Previously here on the site Okunev and East of the Okunev oil exploration regions on the basis of geological and geophysical works we were allocated a pluton granitoids oval size 17x19 km (Ivanov et al., 2003). This array has zonal structure and its central part is composed of monzodiorite, and margin – of granosyenites.

The granosyenites, as representatives of the margin facies of the pluton, selected within the Okunev region (depth 1734 m). The rocks have a massive structure, medium-grained, hypidiomorphic structure. The granosyenites are composed of plagioclase (albite-oligoclase), potassium feldspar, quartz, biotite (annite-phlogopite) and amphibole (ferrous Edenic). Number of colored minerals reaches 7-10%. Among the accessory and secondary minerals, there are titanite, zircon, pyrite, and chalcopyrite. The zircons selected for U-Pb Dating of painted in a greyish-pink color, have a size up to 300 microns. The cathode rays in zircons revealed a complex internal structure. Some crystals are clearly visible growth zones of late generation (Figure 2). Among seven granosyenites, we have analyzed zircon crystals (Table. 1), which was performed 12 isotope definitions. The main part of the ages of the zircons ranges from 291.7 to 309.5 million years, with a mean of 301.6 ± 3.6 million years (Figure 3A). Along with this definition, there are three tests with rejuvenated ages: 181.5; 201 and 213.6 million years, obtained from regions composed of later generations of zircon. These "rejuvenated" age agree rather well with the previously established main stages polyribosome tectonic activity of the West Siberian Plain (Fedorov et al., 2004).

Table 1. U-Pb (SHRIMP-II) isotope data for zircons from granites of the Okunev and East Okunev regions.

Point	$^{206}Pb_c$, %	U,ppm	Th,ppm	$^{232}Th/^{238}U$	$^{206}Pb^*$,ppm	(1)$^{206}Pb/^{238}U$T, MA	(1)$^{238}U/^{206}Pb^*$	±%	(1)$^{207}Pb^*/^{235}U$	±%	(1)$^{206}Pb^*/^{238}U$	±%	Rho
Sample Ok10486/1734													
1.1	0,09	1437	817	0,59	58.1	296.2±5.3	21.26	1.8	0.3391	2.7	0.04703	1.8	0.671
2.1	0,00	1061	516	0,50	44.3	306.2±5.5	20.56	1.8	0.3526	2.5	0.04865	1.8	0.733
2.2	0,28	987	487	0,51	41.0	303.4±5.3	20.75	1.8	0.3459	2.9	0.04819	1.8	0.623
3.1	0,15	563	345	0,63	23.7	308.1±5.6	20.43	1.9	0.3520	3.4	0.04896	1.9	0.551
3.2	0,56	1094	559	0,53	45.3	301.5±5.4	20.88	1.8	0.3460	6.1	0.04789	1.8	0.301
3.3	0,32	1731	1510	0,90	47.2	201.0±3.6	31.58	1.8	0.2274	3.7	0.03166	1.8	0.494
4.1	1,59	1735	954	0,57	51.0	213.6±3.9	29.68	1.9	0.2340	6.3	0.03369	1.9	0.297
5.1	0,25	1081	671	0,64	43.1	291.7±5.3	21.60	1.9	0.3330	4.5	0.04629	1.9	0.414
5.2	0,23	700	292	0,43	29.1	304.2±5.5	20.70	1.9	0.3420	3.9	0.04831	1.9	0.470
6.1	-	1077	572	0,55	45.5	309.5±5.5	20.33	1.8	0.3576	2.4	0.04919	1.8	0.758
6.2	2,29	2164	1337	0,64	54.3	181.5±3.4	35.03	1.9	0.1770	8.1	0.02855	1.9	0.231
7.1	2,07	1132	573	0,52	46.6	295.7±5.3	21.31	1.8	0.3390	5.1	0.04693	1.8	0.363
Sample Vok10484/1601													
1.1	0.22	569	240	0.44	24.2	310.7±5.1	20.25	1.7	0.3560	3.6	0.04938	1.7	0.463
1.2	0.45	1042	704	0.70	42.6	298.8±4.4	21.08	1.5	0.3380	3.5	0.04744	1.5	0.437
2.1	0.00	648	312	0.50	27.5	311.0±5.1	20.23	1.7	0.3584	2.6	0.04943	1.7	0.638
3.1	0.17	2330	1565	0.69	91.6	287.8±4.1	21.90	1.5	0.3257	2.4	0.04566	1.5	0.606
3.2	0.12	1163	668	0.59	47.0	295.7±4.4	21.30	1.5	0.3377	2.5	0.04695	1.5	0.607
4.1	0.26	822	365	0.46	34.4	306.0±6.8	20.57	2.3	0.3440	3.8	0.04860	2.3	0.609
4.2	0.00	1827	1672	0.95	73.8	296.0±4.3	21.28	1.5	0.3416	1.9	0.04699	1.5	0.779
5.1	0.00	1381	673	0.50	56.2	298.3±4.4	21.11	1.5	0.3393	2.1	0.04737	1.5	0.730
6.1	1.03	5301	9040	1.76	55.0	76.6±1.2	83.70	1.6	0.0979	5.4	0.01195	1.6	0.306
7.1	0.19	210	54	0.26	8.82	306.9±5.5	20.51	1.8	0.3490	5.0	0.04876	1.8	0.367

Note: deviation is ±1σ; Pbc and Pb* - common and radiogenic lead, respectively; the deviation of calibration with respect to standards of 0.29%; (1) correction using 204Pb. T – age; Rho – correlation coefficient of the ratios 207Pb*/235U–206Pb*/238U. Processing of experimentally obtained U-Pb data and plotting with concordia was carried out using the programs ISOPLOT/EX ver.3.66.

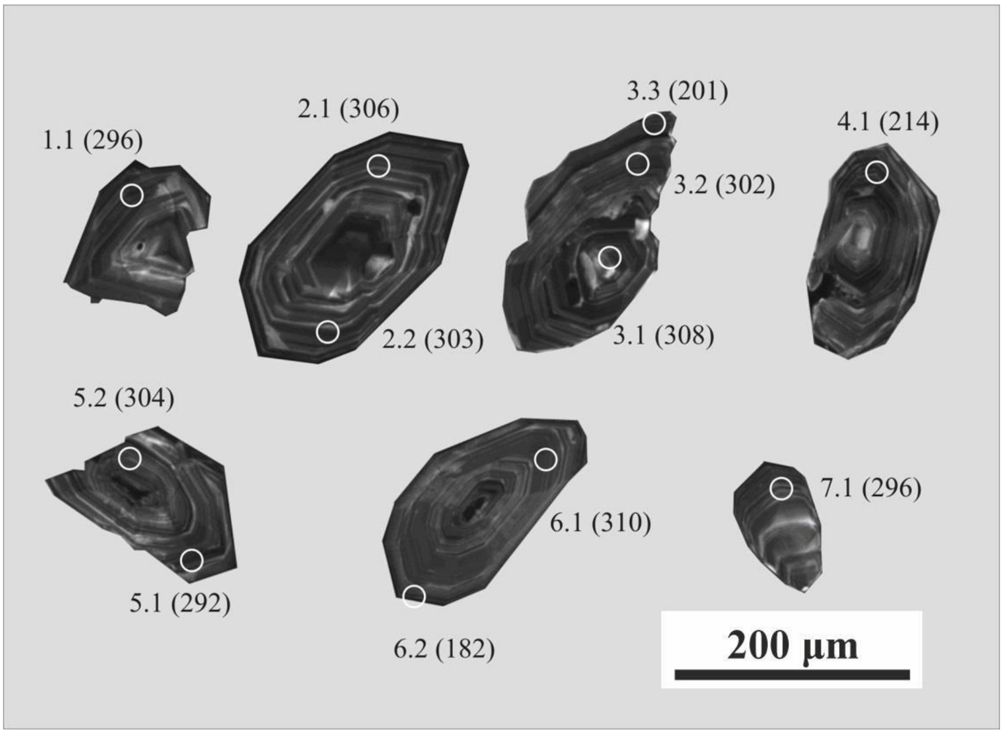

Figure 2. Zircons from granosyenite of Okunev region and Shaim district (hole Ok 10486, 1734 m deep), circles show the positions of the analyses, age is shown in parentheses (MA).

Monzodiorites, composing the Central part of pluton, taken within the East Okunev region (well Ok 10484, depth 1601 m). The rocks consist of plagioclase (andesine-oligoclase), potassium feldspar, biotite (ferrous phlogopite), amphibole (edenite, magnesian hornblende), and quartz. There are also titanite, herpetic, zircon, ilmenite and pyrite. The zircons selected for U-Pb Dating, painted in pale pink color, have a size of up to 200 μm. The cathode rays in zircons revealed a complex internal structure. Some crystals clearly visible rhythmic zonation, in other rhythmic zoning is absent. Moreover, we observed crystals with distinct drill samples and growth zones of the late generation. We analyzed seven crystals of zircon from quartz monzodiorite, which was carried out 10 isotope samples (see table. 1). A concordant ages are in the range from 296 to 311 million years, with a mean of 300.5 ± 3.0 million years (Figure 3b).

Thus, U-Pb dating of the rocks have a very close age (Figure 3); quartz monzodiorite (300.5 ± 3.0 million years), and granosyenite (301.6 ± 3.6 million years). This apparently implies that, despite the zonal structure, the whole mass of granite, crystallized in the late Carboniferous and this allows us much greater confidence to say that the introduction of the rest subalkaline monzodioritegranosyenites arrays Shaim-Kuznetsov anticlinorium occurred in the late Carboniferous. At Petro-geochemical characteristics, these granitoids belong to monzodiorite-granite series (Ivanov et al., 2009).

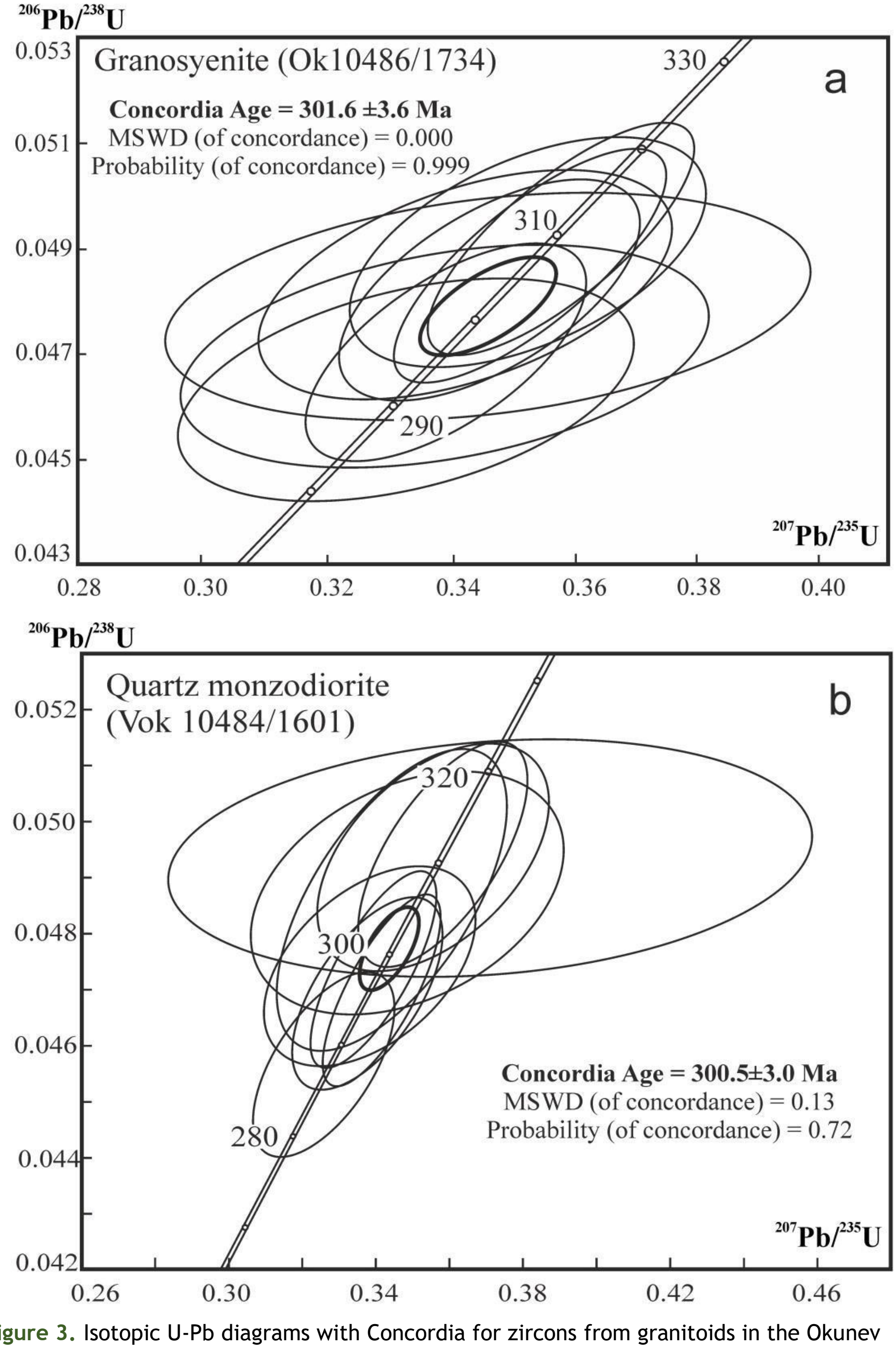

Figure 3. Isotopic U-Pb diagrams with Concordia for zircons from granitoids in the Okunev (a) and East Okunev (b) regions.

In addition, we obtained dating of metamorphic rocks from the framing of granite blocks. Within the basement of the Shaim district, the quartz-sericite, sericite-quartz, plagioclase-quartz-sericite, zoisite-chlorite-amphibole-quartz and phlogopite-Muscovite-quartz rocks were opened. For research were selected twomica slates of Tolansky region of 10804 wells (with a depth of 1768 metres) and 1857 (from a depth of 1738 m), which are composed of white mica (Muscovitealumosilicone), phlogopite and quartz, chlorite (clinochlore-chamosite)), albite (An0-3), tremolite and epidote. Accessories are represented by

fluorapatite, titanite and rutile. In addition, sulphide mineralization is noted – pyrite, chalcopyrite, pyrrhotite and cobaltite.

Zircons from the sample To1857/1738 have a size of from 50 to 200 µm, pink color and rhythmically zoned internal structure, often with sectoriality (Figure 4). The crystals are well cut, have a prismatic habitus, sometimes with the development of two bipyramids and basal plane. Seven crystals of zircon were analyzed (Table 2). Most concordat ages were about 369-395 million years (Figure 5A), but there are single old and young datings: 2709, 503, 426, 261, and 295 million years.

Table 2. U-Pb (SHRIMP-II) isotope data for zircons from two-mica shale rocks of Shaim region.

Point	$^{206}Pb_c$, %	U, ppm	Th, ppm	$^{232}Th/^{238}U$	$^{206}Pb^*$, ppm	$(1)^{206}Pb/^{238}U$T, MA	$(1)^{238}U/^{206}Pb^*$,	±%	$(1)^{207}Pb^*/^{235}U$,	±%	$(1)^{206}Pb^*/^{238}U$,	±%	Rho
Sample To10804/1768													
1.1						364.9±5.6	17.10	1.6	0.4290	4.2	0.058		
2.1	0.40	230.7	153.4	0.69	12.1	380.7±6.0	16.37	1.6	0.4470	6.3	0.06084	1.6	0.257
2.2	0.20	199.9	150.9	0.78	9.8	357.7±5.6	17.49	1.6	0.4250	4.3	0.05706	1.6	0.371
3.1	0.08	443.8	310.8	0.72	22.0	361.8±5.1	17.31	1.5	0.4360	2.8	0.05773	1.5	0.522
4.1	0.14	445.9	397.5	0.92	23.6	385.0±5.5	16.23	1.5	0.4620	2.8	0.06154	1.5	0.530
5.1	0.15	538.1	353.7	0.68	27.9	377.6±5.3	16.55	1.4	0.4480	2.9	0.06032	1.5	0.507
6.1	0.17	416.6	163.9	0.41	20.7	362.1±7.6	17.28	2.2	0.4310	3.4	0.05780	2.2	0.639
7.1	0.14	636.7	328.6	0.53	33.0	377.5±5.3	16.56	1.4	0.4520	2.4	0.06030	1.4	0.597
8.1	0.12	960.4	672.7	0.72	49.4	374.2±5.0	16.71	1.4	0.4509	2.0	0.05977	1.4	0.682
9.1	-	180.4	29.8	0.17	11.3	453.4±7.8	13.72	1.8	0.5720	3.2	0.07290	1.8	0.563
10.1	-	899.7	569.4	0.65	44.8	363.1±5.3	17.26	1.5	0.4294	2.1	0.05794	1.5	0.737
Sample To1857/1738													
1.1	0.17	358.5	372.6	1.07	19.5	395.5±6.1	15.78	1.6	0.4670	3.2	0.06330	1.6	0.489
2.1	0.43	1356.3	354.2	0.27	48.4	261.2±3.7	24.08	1.4	0.3370	3.2	0.04135	1.5	0.456
2.2	0.41	314.3	119.6	0.39	16.0	369.2±5.8	16.89	1.6	0.4250	4.7	0.05894	1.6	0.339
3.1	0.16	173.5	163.7	0.97	9.0	377.4±6.1	16.56	1.7	0.4440	4.1	0.06030	1.7	0.400
3.2	-	645.2	341.9	0.55	34.0	383.6±5.3	16.31	1.4	0.4621	2.0	0.06131	1.4	0.698
4.1	0.05	335.2	152.6	0.47	17.5	380.7±5.6	16.43	1.5	0.4610	2.7	0.06084	1.5	0.559
5.1	0.04	1666.9	367.9	0.23	67.0	294.7±4.0	21.37	1.4	0.3562	1.7	0.04678	1.4	0.793
6.1	-	152.0	154.4	1.05	68.2	2709.0±3.3	1.920	1.5	13.45	1.7	0.52240	1.5	0.909
6.2	0.28	328.5	104.4	0.33	19.3	426.0±6.7	14.60	1.6	0.5540	3.5	0.06830	1.6	0.470
7.1	-	102.7	117.9	1.19	7.1	502.6±8.9	12.40	1.8	0.6750	7.5	0.08110	1.8	0.246

7.2	0.01	701.0	348.5	0.51	36.3	377.0±5.2	16.60	1.4	0.4481	2.1	0.06023	1.4	0.694

Note: Pbc and Pb* - common and radiogenic lead, respectively; the deviation of calibration with respect to standards of 0.56%; (1) correction using 204Pb. T – age; Rho – correlation coefficient of the ratios 207Pb*/235U–206Pb*/238U. Processing of experimentally obtained U-Pb data and plotting with concordia was carried out using the programs ISOPLOT/EX ver.3.66.

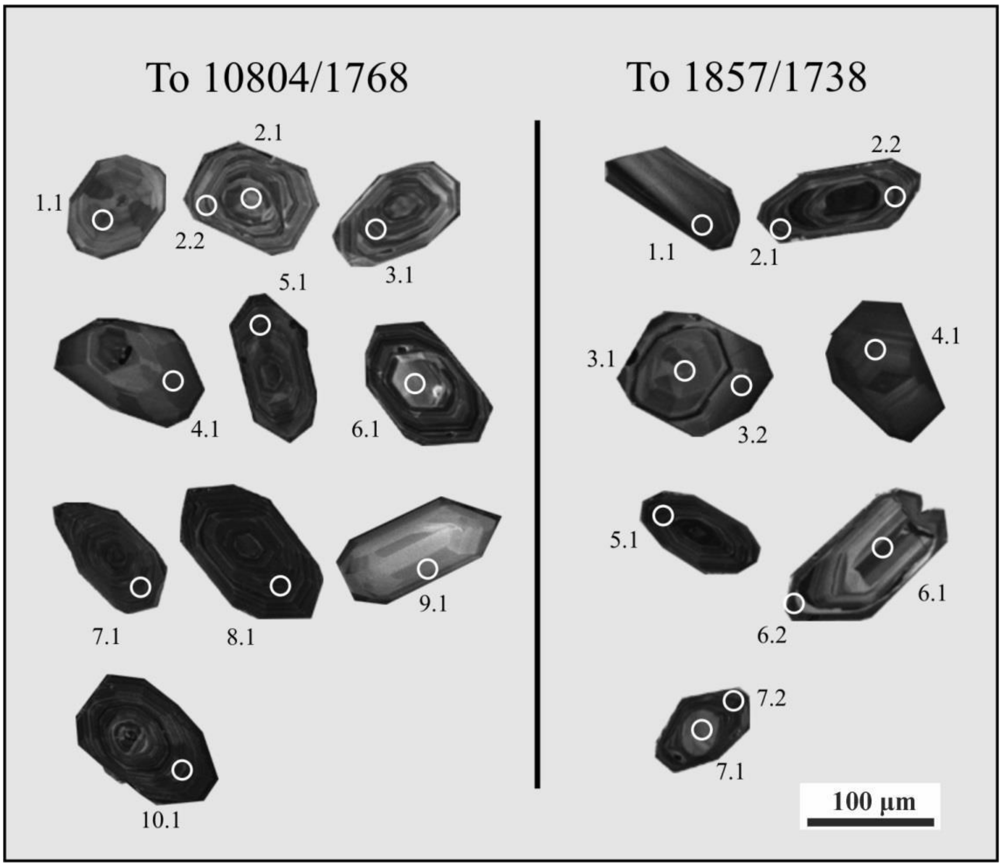

Figure 4. Cathodoluminescent images of zircon crystals in samples To1857/1738 and To10804/1768. Circles show the location of the measurements; the numbers refer to analyses in Table 2.

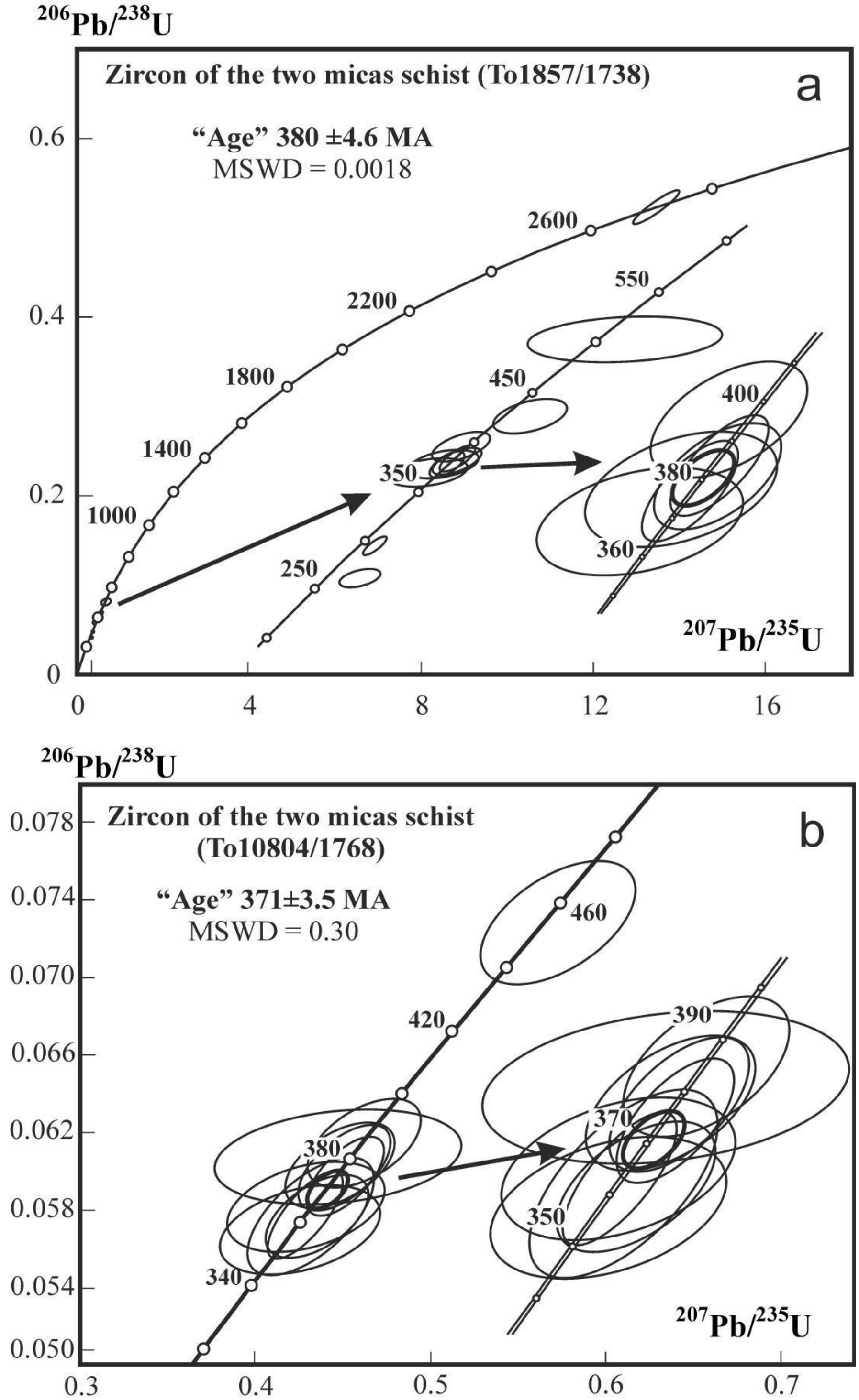

Figure 5. Isotopic U-Pb diagram with Concordia for zircons of two-mica shale (samples To 1857/1738 (a) and To 10804/1768 (b)).

In the sample To10804/1768, zircons are light pink in color, grain size 60 to 170 μm. Zircon found in the form of well-faceted prismatic crystals, sometimes with the development of basal plane (Figure 4). We analyzed 10 crystals of zircon (tab. 2). Almost all the dates obtained went to Concordia in the region 358-385 million years (Figure 5B) and give the conditional average age is 371±3.5 million years, with the exception of one more ancient crystal 453 million years.

The most "ancient" datings were obtained in the Central parts of crystals and probably are xenogenic. Single "young" Datings - 295 and 261 million years in

accordance with the previously obtained K-Ar data for the quartz-sericite shale rocks (277-302 million years (Ivanov et al., 2005)) are interpreted as age of metamorphism of these rocks, which is close to the time of formation of monzodiorite-granosyenites arrays of Shaim region (Ivanov et al., 2010; Ivanov et al., 2011).

This implies that a large part of the protolith for metamorphic rocks of the Shaim-Kuznetsov anticlinorium is, apparently, from the late middle Devonian age (395-358 million years), which is consistent with the previously obtained Dating U-Pb by method ID-TIMS on zircons from the quartz-sericite slates ShaimKuznetsov anticlinorium (Ivanov et al., 2005). To determine the substrate, we used a chart FAK (Peredovskiy, 1980), which is used for the reconstruction of primary aluminium-silicate composition of metamorphosed igneous and sedimentary rocks. Compositions of the studied metamorphic rocks of the ShaimKuznetsov meganticlinorium form a narrow range of values and are in the greywacke and melanowacke alteration. Themselves greywackes were formed, probably by local erosion of rocks of ophiolitic association. This is evidenced by the fact that the zircons in both samples have a typical magmatic appearance, and in which there is no trace of roundness. Metamorphic transformation of rocks occurred under green shale rock and lower amphibolite facies in late Carbonous early Permian time (Ponomarev, 2011).

Thus, the anticlinoria kernels of the greatest part of Western Siberia (especially its Western half) were stacked, apparently, not by Precambrian, but by Paleozoic magmatic and metamorphic complexes, i.e., the formations of the lower and middle part of the crust.

The obtained results allow clarifying the formation history of metamorphic basement rocks of the West Siberian Plain.

The Geological Basement Structure of the Eastern Part of Western Siberia

On the basis of generalization and analysis of all geological and geophysical data, we have compiled a new version of the geological map of pre-Jurassic base of Eastern Khanty-Mansiisk Autonomous district (Figure 6). To create this map, we used to map the gravitational and magnetic fields at scales of 1:200000, time sections and their special transformation on margin seismic profiles, data for all drilled wells and the results of our study of drill-hole cores. This resulted in the new version of the model of the structure, properties and geodynamic state of the pre-Jurassic base of the Eastern part of the Khanty, significantly refining the cards predecessors, (Eliseev et al., 2006; Eliseev et al., 2008; Surkov, 1986). Scale builds corresponds to the level of 1:500000, but in parts of some regions "correspond" to this level of density of coating wells of exploratory drilling.

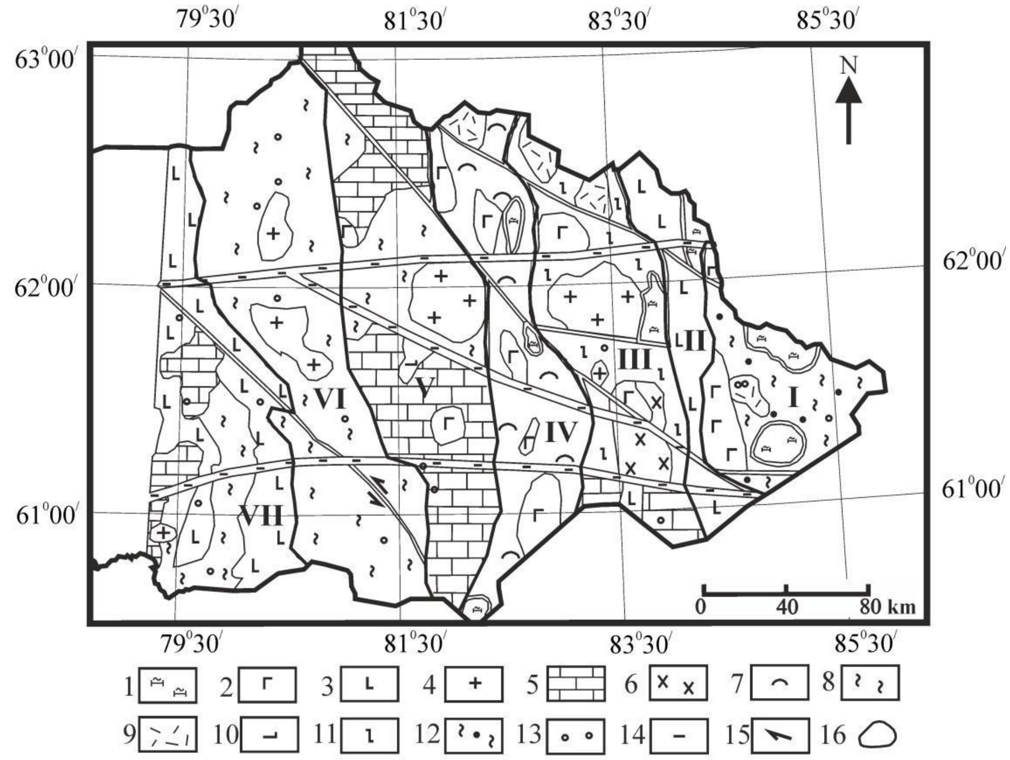

Figure 6. Geologic map of pre-Jurassic base of the Eastern part of Khanty-Mansiisk Autonomous district -Yugra (K. S. Ivanov, V. B. Pisetski).

On the basis of the research, a new version of the geological structure of the territory was proposed, the mapping image of which is shown in Figure 6.

Within the study region, we have identified eight submeridional structuralformational zones (SFZ), with different sets and structures composing these formations, history of geological development and consequently, the physical fields. The large structural forms in the sedimentary cover are genetically linked to structural-formational zones, which are consolidated in the basement of the young platform and buried under sedimentary cover. Therefore, the distinction between SFZ is of interest not only for tectonic reconstruction of the Paleozoic era, but also for petroleum geology. Judging by the sharp change of lithology of the rock complexes and the nature of physical fields (matrices geodynamic models, in particular), we believe that all the submeridional contacts between the SFZ within the studied region are tectonic. From East to West, we distinguish the following structural-formational zones:

1. *Tyniar* (marked by Roman number I in Figure 6), composed predominantly of terrigenous-siliceous black shale formation of the middle Paleozoic with the bodies of granites, rhyolites, gabbros, gabbro-diorite and serpentinite blocks in the margin parts of the zone. The region is characterized by high values of gravity field and strongly varying alternating magnetic field, which reaches 400 nT or more, over arrays of serpentinites. In the zone, there are two drilled wells in Tyniar region, No. 100 and 101, which revealed granitoids, and partly enclosing sedimentary depth. We carried out detailed isotopic and geochronometric studies of siliceous volcanic rocks and granitoids on Tyniar region by 4 methods: K-Ar, Rb-Sr, Sm-Nd and U-Pb (SHRIMP-II on zircon). In the U-Pb system of zircons of Tyniar region granitoids (Figure 7), we fixed not less than a two-stage geological history (Ivanov & Erokhin, 2011). Event with age about 277 million years (the lower intersection of Concordia and Discordia), obviously correlated with the phases of the igneous implementation and solidification of subvolcanic graniteliparite body. This definition is well correlated

with the potassium-argon age of this body; 3 of 5 definitions (notably of species with high content of potassium) gave 268, 270 and 272 million years. Event with age about 2051 ± 23 million years (the upper intersection of Concordia and Discordia) indicates that the late Paleozoic (early Permian) granite magma interacted with the ancient substance of this age. It is most likely that it was an ancient granite-metamorphic basement, as a result of partial melting which formed Tyniar Liparit granite body.

2. *Lekos* (marked with Roman numbers II in Figure 6), folded with rather fresh basalts, with a capacity of more than 200 m, which are landed with ash calc sinters (xenosinters) of basaltic composition with interlayers of metamorphosed argillites, sandstones and gravelites, with a capacity of more than 400 meters. The region is characterized by weak positive homogeneous field of gravity and a uniform weak negative magnetic field. All mentioned complexes were encountered by the Lekos well 27 (Eliseev et al., 2009; Bochkarev et al., 2010). Triassic volcanic rocks are exposed in the interval of 2485-3110 m.

Range of 2485-2700 m – subalkaline olivine basalts, in sections amygdaloidal, sometimes hydrothermally altered, brecciated. In the range of 2570-2577.5 m, we marked homogeneous dolerites with a low content of volcanic glass (probably subvolcanic). The found biotite confirms their assignment to subalkaline differences. The volcanics contain bytownite (in phenocrysts), labrador (in microlites), augite, and magnetite. Volcanic glass and olivine are usually completely replaced by carbonate material. Tonsils usually are composed of chalcedony-carbonate cement, sometimes with a small amount of chlorite.

Below the cut, there are the brecciated reddish basaltoids (hematitized); cement of breccias is represented by carbonate. Next, in the range of 2630-2700 m there are marked highly altered basalts, representing the lower part of extruded sheet. These volcanic rocks are intensively carbonatized, in some breeds, only relics of rock-forming minerals are stored (usually plagioclase and magnetite).

Range of 2700-3110 m – ash calc sinters (xenosinters), dark-gray to black basaltic composition with fragments of mainly sedimentary rocks the gravel-sand size. The texture is spotty, sometimes brecciated. Structure is ashy, fine and medium detrital. There are traces of hematitization and carbonatization and sometimes interlayers of metamorphosed argillites, siltstones, sandstones and gravelites, introduction of basalts. In the range of 2710-2716 m, flora and fauna of the Triassic age are discovered (Eliseev et al., 2009).

Below the cut, there are sedimentary rocks (argillites, sandstones, conglomerates, etc.) of the Paleozoic era, including Ordovician time.

3. *Kys-Egan* (Kys-Egan uplifting, marked with Roman numbers III in Figure 6), is formed, apparently, by metamorphic chlorite-albite-quartz shale rock (green shale rock facies; possibly Precambrian), which contain a large Intrusive blocks of granites, rhyolites, gabbros, gabbro-diorites, diorites (and serpentinites in the marginal Eastern part of the zone). This zone is characterized by very low margin gravity field (which reaches its minimum over major sub-isometric Kys-Egan granite block) and strongly varying of alternating magnetic field. Here, a well KysEgan 91 was drilled, but its drill sample in the range of 2397-2400 m is not raised (Figure 6). The age of Precambrian rocks of Kys-Egan region was adopted presumably, this is supported by the presence of Precambrian zircons in granites of Tyniar zone (see above).

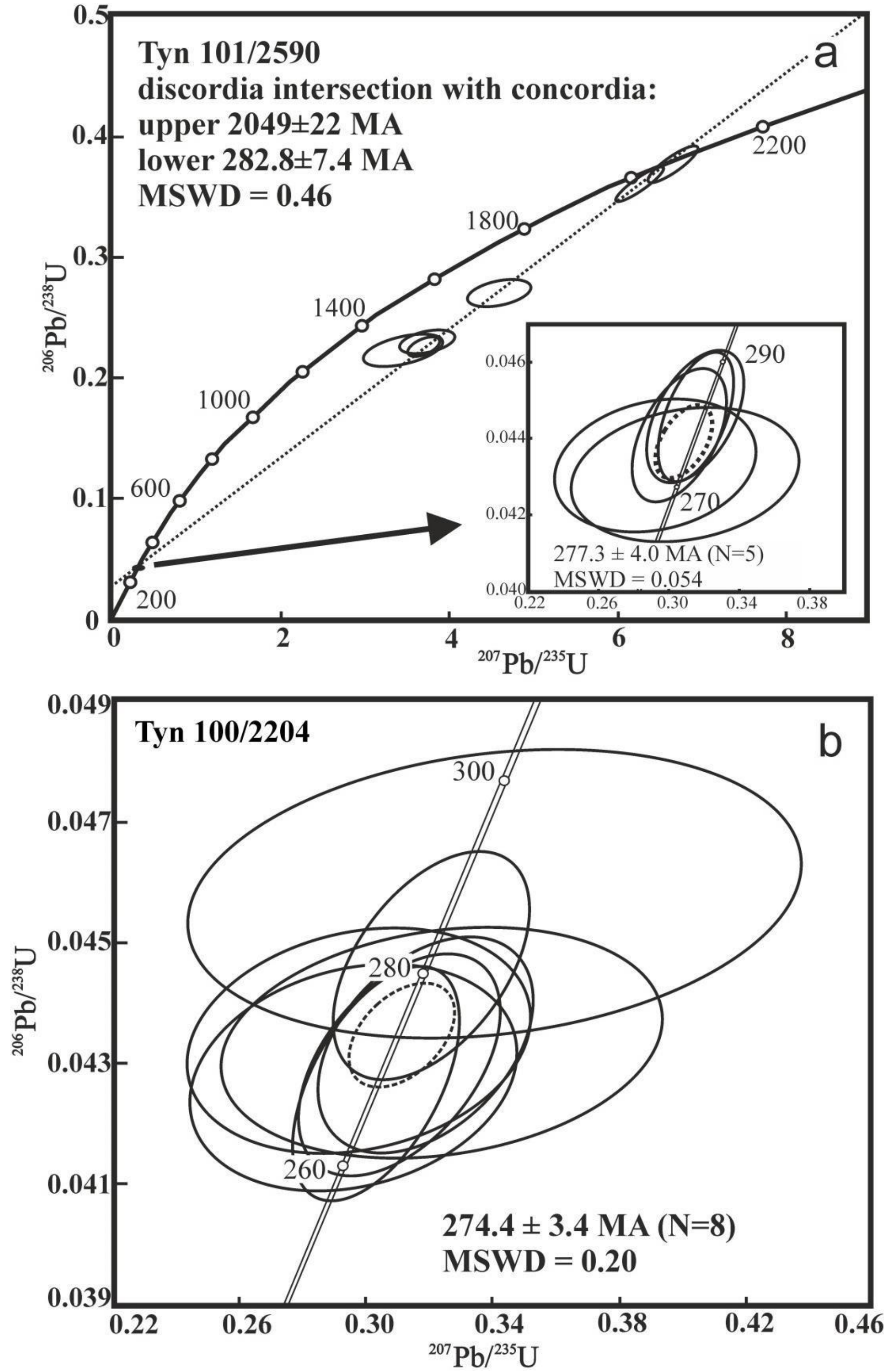

Figure 7. Isotopic U-Pb diagrams with Concordia for zircons from Tyniar region granitoids (samples Tyn 101/2590 (a) and Tyn 100/2204 (b)).

4. *Vakhsky* (Vakhsky deflection, marked with Roman number IV in Figure 6). The structure of this zone, apparently, is dominated by volcanogenicsedimentary and sedimentary depth, probably of lower-middle Paleozoic, containing rather numerous body of gabbros, serpentinites and one large acid of body composition in the North zone. The region is characterized by slightly elevated values of gravity field and variable, mainly positive magnetic field, which reaches 400 or more nT over eight anomalies over the blocks of serpentinites and gabbroids, which account for about 40% of the region of the zone. Here, a well KysEgan 90 was drilled, where the range from 2316.3 m to 2408 m

(bottom) revealed a strong massive shale, gray, dark gray and black with poorly expressed layering, probably siliceous.

5. *Pylkaramin* region (marked with Roman number V in Figure 6). The largest part of this zone (its southern half and Northern quarter) established a large carbonate blocks of Devonian age folded shallow-water limestones, among which the well is dominated by stagnant, backreef sediments. Between these carbonate blocks in the Northern part of the zone, there is a large block of mainly deeper-water siliceous-terrigenous black shale depth that are broken by the granite block. For the carbonate blocks within this region, very high values of the gravity field in combination with a very low magnetic field values are typical; siliceous-terrigenous depth are characterized by moderately elevated or moderately low values of gravity field. Within this zone, the drilled wells are: Laryngolkuisk 14, Upper-Sabunska 9, Kulynigol 30, North-Megtygegan 33, Eastern- Pylkaramin 11, South- Pylkaramin 22, Eastern-Sabunska 7.

The study of drill-hole cores of Pylkaramin zone gave the following results:

In the Konjikala 30 well, an imposing complex of conodonts of the upper Devonian was installed as a result of dissolution of limestone samples in the interval 2692-2700 m.

In the North-Megtygegan 33 well, a rich complex of conodonts, algae, and foraminifera Famennian stage is set in the interval 2840-2850 m in dark grey fine-grained limestone. Carbonate rocks of cut in this well are characterized by monofacial composition of precipitation, namely organogenic-peloid wackstones. Their rock-forming components are peloids and diverse organic residues, such as blue-green algae Issinella, Camaena, crinoidea, needles of sea urchins, tentaculites, brachiopods, gastropod, ostracods, foraminifers Archaesphaera magna Sul., A. grandis Lip., Parathuramminites sp. P. cf. paulis Byk. Parathuramminites ex gr. suleimanovi (Lip.), Vicinesphaera squalida Antr. The formation of these species occurred in the shallow and hydrodynamically quiet (isolated) environment.

6. *Borov* region (marked with Roman number VI in Figure 6) is composed of relatively deep-water (bathyal continental slope) siliceous-terrigenous black shale formation that is broken in two granite blocks. Among these depth, body of limestone is well marked, not creating features in geophysical fields of 1:200,000 scale, which testifies to their low power. Today, it is impossible to exclude the suggestions that these limestones may be landslide erratic mass of the more shallow region of the pool (from Pylkaramin zone) or may be formed with the small local uplifts. The region is characterized by a rather homogeneous gravity and magnetic fields (mainly with low values). Within this zone, the drilled wells are: Borov 6 and 7, North-Borov 1, South-Lariak 28, Kolunigol 26, Megegan 27, Pylkaramin 1 and 2, Ulymtor 31, Kulynigol 2, Granat 18, Sykhtin 500, Lungegan 3, Priozernaya 91, 92, South-Priozernaya 93 and 95, North-Priozernaya 4, Vasakhin 102. The study of the petrography and geochemistry of drill-hole cores upland zone showed that it is composed of relatively deep-water (bathyal continental slope) siliceous-terrigenous black shale depth.

7. *Sabunska* zone (Triassic graben, sometimes also called Khokhryakov) is located directly west of our map, composing the North-North-West line. It is uncovered by the following wells: Ilichev 110, North-Sabunska 2, Sabunska 1, Istochninska 118, Lariak 1 and Vladylenskaya 1, where in the range of 30633151.5 m (bottom), the following are drilled:

Range of 3063-3070 m – red fine-grained sandstones

Range of 3070-3074 m – similar sandstones, apparently volcanic

Range of 3112-3120 m – fresh dark green massive and amygdaloidal basalts of the Trias, shaped with laths of plagioclase, 6-8 mm in size.

Range of 3147-3151.5 m – green and red-brown fine-grained sandstones and siltstones with numerous rounded nodules and rare brachiopods.

The study of petrography, geochemistry and age of basaltoids, uncovered by wells within Sabunska zone (and the carried out x-ray diffraction study) showed that these volcanic rocks are almost completely converted by imposed lowtemperature hydrothermal changes. However, the geochemistry of the basalts of the North-Sabunska zone is sufficiently well-correlated with similar trends in basalts from the North-Sosvin Triassic graben with reliable isotopic datings. This indirectly confirms that the original age of altered basalts also belonged to the Triassic era. It is reported by (Bochkarev, Brekhuntsov, 2011) that in the penultimate interval basalts have K-Ar age of 229±10 million years, however, this age is clearly rejuvenated (Medvedev et al., 2003; Ivanov et al., 2005).

8. *Kotygiegan* zone can be traced directly to the West of Sabunsky graben and is dominated by shallow-water limestones of the upper Devonian period. Here, the drilled wells are Kotygiegan 22, 23, 26, 28 and East Khokhryak 1.

Microfacies analysis of the carbonate section of the Kotygiegan 26 well allows evaluating the conditions of accumulation of sediments that form these deposits as shallow and hydrodynamically active. This is also seen by the composition of the biocenosis (oryctocoenosis), which is fairly uniform throughout the section and presented, including, and shallow forms of organisms, such as blue-green algae, brachiopods, amphipores. The complex of provided foraminifera cuts of Archaesphaera minima Sul., A. grandis Lip., A. magna Sul., Auroria ferganensis Pojark., Bisphaera minima Lip., B. elegans Viss., Calcisphaera rara Reitl., Diplosphaerina sp. Parathuramminites sp. Parathuramminites suleimanovi (Lip.), Parathuramminites ex gr. suleimanovi (Lip.), P. scutulus (Tchuv.), P. obnatus (Tchuv.), Radiosphaera ponderosa Reitl., Vicinesphaera squalida Antr., V. angulata Antr. indicates a late Devonian age of the rocks.

Held tectonic zoning of the basement of the East Khanty-Mansiisk Autonomous district with the release of eight structural-formational zones reflects the fundamental features of the model structure, properties and geodynamic state of the pre-Jurassic base of the region, which together with the results of geodynamic and fluid dynamic analysis allows moving the objective to a more detailed mapping and determination of the territory gas and oil potential.

Discussion and Conclusion

As a result of mapping and detailed geological-geophysical study of the major segments of the pre-Jurassic base of West Siberian Plain, the following main results were obtained.

In the Western half of the region:

For the first time in metamorphic rocks from the basement of the West Siberian Plain, the obtained U-Pb Dating (SHRIMP-II on zircon). It is established that a large part of the protolith of the metamorphic depth of the ShaimKuznetsov meganticlinorium was folded by sedimentary late - and middleDevonian rocks (395-358 million years). Probably, greywackes served as a substrate of metamorphic rocks, which depth were formed largely in the erosion of rocks of ophiolitic association, described in the region (Ivanov et al., 2004). This is also evidenced by the fact that in general, the zircons in both samples have a typical magmatic appearance, in which there is no trace of roundness (the shift in the composition of the fragments). Metamorphic transformation of rocks occurred under green shale rock (sometimes bottoms of amphibolite) facies of metamorphism in late Carbonous - early Permian time.

The late carbonous age of granite plutons composing the Shaim-Kuznetsov meganticlinorium was revised by U-Pb method (SHRIMP-II on zircons).

The new results significantly clarify the history of the basement formation of the West Siberian oil and gas megabasin. It turns out that the anticlinoria kernels are not the pre-Cambrian blocks (median blocks, uplifts of the ancient Proterozoic proto-crust, etc.), but the Paleozoic magmatic and metamorphic complexes, i.e., the formations of the lower and middle part of the crust. Based on available data, their emergence to the surface (or upper crust) occurred during the early Triassic rifting and stretching of Western Siberia, i.e. in the initial period of the formation of the West Siberian oil and gas megabasin.

In the Eastern part of Western Siberia:

The tectonic zoning of the East Khanty basement is held and eight submeridional structural-formational zones (SFZ) are dedicated, with different sets and structure composing these formations, history of geological development and consequently, the physical fields. It is important that the large structural forms in the sedimentary cover are genetically linked to structural-formational zones, which are consolidated in the basement of the young platform and buried under sedimentary cover. Judging by the sharp change of lithology of the rock complexes and the nature of physical fields (integral matrix of potential fields and reliefs of the boundary surfaces), we should assume that all the submeridional contacts between the SFZ within the studied region are tectonic.

The presence of ancient (about 2 billion years) sialic basement under Tyniar region is highly likely. Here, the first geochronological formations dating of the basement of all Western Siberia is obtained.

Therefore, we carried out an integrated study of petrography, petro- and geochemistry, biostratigraphy, and geochronology and isotopy of pre-Jurassic formations in the Eastern part of the Khanty-Mansiisk Autonomous district.

On the basis of generalization and analysis of all geological and geophysical data, we have compiled a new version of the geological map of pre-Jurassic base of the Eastern part of the Khanty-Mansiisk Autonomous district, scale 1:500,000, with insets of larger scale. To create these maps we used the gravitational and magnetic fields at scales of 1:200000, time sections and their special transformation on margin seismic profiles, data for all drilled wells and the results of our study of drill-hole core. This resulted in the new version of the model of the structure, properties and geodynamic state of the pre-Jurassic base of the Eastern part of the Khanty-Mansiisk Autonomous district significantly refining the predecessors' maps.

Implications and Recommendations

We have prepared a new version of the geological map of pre-Jurassic base of the Eastern part of the Khanty-Mansiisk Autonomous district, which will be very useful later in the in this region of geological exploration and field drilling. Based on the developed maps of scale 1:500000, in the future, it will be possible to create larger scale geological maps of the pre-Jurassic basement of the Khanty-Mansiisk Autonomous district. We obtained data on the structure of the pre-Jurassic base of Western Siberian megabasin and they may become the basis for prediction and search in the territory of hydrocarbons deposits in deeper horizons, the industrial development of which is planned for the next decades.

Acknowledgements

For many years, we carried out the study of the basement of the Western half of Western Siberia jointly with the famous petroleum geologist Yuri Nikolayevich Fedorov. The authors express their sincere appreciation to the Deputy Director of the V.I.SHPILMAN RESEARCH AND ANALYTICAL CENTRE FOR THE

RATIONAL USE OF THE SUBSOIL, V. A. Volkov for consultation and discussion of the results in the East of the Khanty-Mansiisk Autonomous district. We thank V. B. Pisetsky for the invaluable help in the carrying out of works, N. V. Rodionov (CIR VSEGEI) for analyses of zircons, T. I. Stepanova (Geology and Geochemistry Institute in the Ural Branch of the Russian Academy of Sciences) for determining the fauna and V. S. Bochkarev (JSC Siberian Scientific and Research Centre) for constructive comments.

The work is executed at financial support of Russian Scientific Foundation (No. 16-17-10201).

Disclosure statement

No potential conflict of interest was reported by the authors.

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